J Paleolimnol (2010) 44:243–251
DOI 10.1007/s10933-009-9400-1

ORIGINAL PAPER

Reconstructing temperature at Egelsee, Switzerland, using North American and Swedish chironomid transfer functions: potential and pitfalls

Isabelle Larocque-Tobler

Received: 5 June 2009 / Accepted: 29 November 2009 / Published online: 5 December 2009

Abstract The temperature reconstruction obtained from chironomids preserved in the sediment of Egelsee, Switzerland, was partially flawed by the low percentages of fossil taxa represented in the Swiss calibration set (Larocque-Tobler et al. 2009a). Transfer functions (TFs) from other regions, which allow a good representation of the fossil taxa (>80%), could be applied to the fossil assemblages of Egelsee. First, the validity of using two (a Swedish and a North American (NA)) TFs was tested by comparing the chironomid-inferred temperatures with instrumental data. Since good relationships ($r_{\text{Pearson}} = 0.71$ and 0.61, $p = 0.001$ for the NA and Swedish TFs, respectively) were obtained, these two models were used to reconstruct the Late Glacial and early Holocene periods at Egelsee. Reconstructions using both models showed clear cold periods during the Younger Dryas and the so-called 8,200 calibrated years BP event. However, the amplitude of changes during these periods was higher when the NA transfer function was used, probably due to the fact that 37% of the taxa in the core had temperature optima colder in the NA than in the Swedish and Swiss models. The results indicate that TFs from other regions can be applied when they are based on samples with good modern analogues, however, caution should be taken when the amplitude of temperature changes is considered.

Keywords Non-biting midges · Calibration sets · Temperature reconstruction · Late Glacial · Early Holocene · *Corynocera ambigua*

I. Larocque-Tobler (✉)
Oeschger Center for Climate Change Research, University of Bern, Zähringerstrasse 25, 3013 Bern, Switzerland
e-mail: larocque@giub.unibe.ch; isabelle_larocque@ete.inrs.ca

I. Larocque-Tobler
Institut National de Recherche Scientifique, Centre Eau, Terre et Environnement, 490 De La Couronne, Québec, QC G1K 9A9, Canada

Introduction

Subfossil chironomids preserved in the sediment of Egelsee, Switzerland, were previously used to reconstruct mean July air temperatures (Larocque-Tobler et al. 2009a). A major problem associated with using the Swiss transfer function to infer temperatures was that many of the Late Glacial and early Holocene samples had high percentages of *Corynocera ambigua*, a taxon that was not present in the training set lakes. The fossil assemblages were thus composed of taxa poorly represented (<60%) in the calibration set, and the reconstructed temperature changes based on these poorly represented samples were of lower amplitude than expected (Larocque-Tobler et al. 2009a). Considering the availability of other calibration sets with *C. ambigua*, the question posed here is: would the reconstruction be more accurate if a transfer function (TF) offering a better representation of taxa in the fossil samples were used?

The applicability of using a training set from one region to reconstruct climate in another region was assessed by Lotter et al. (1999). They used both a North American (Walker et al. 1997) and a Swiss calibration (Lotter et al. 1998) model to reconstruct the Late Glacial changes in a North American site (Splan Pond; Levesque et al. 1996) and at a Scottish site (Whitrig Bog; Brooks and Birks 2000). The temperature changes during the Late Glacial at both sites showed similar patterns, however, the amplitude of change varied from 2 to 6°C during the Late Glacial, depending on the model used. Only by comparing the reconstructions with other independent records can it be determined which of the models is more accurate. Such a comparison will be attempted here.

In the absence of calibration sets from the studied area, many quantitative temperature reconstructions have been obtained using a TF from another region. For example, a Norwegian training set was used to reconstruct the climate at Whitrig Bog, Scotland (Brooks and Birks 2000) and at Talkin Tarn, Northern England (Langdon et al. 2004), a Swiss TF was used to reconstruct climate in France (Heiri and Millet 2005) and a Swedish TF to reconstruct temperatures in various Russian lakes (Andreev et al. 2004, 2005; Ilyashuk et al. 2005) and in Italy (Larocque and Finsinger 2008). When the taxonomy is harmonized between the calibration set and the fossil record, the reconstruction might be appropriate (Brooks and Birks 2000; Langdon et al. 2004). However, Heiri and Millet (2005) and Andreev et al. (2004, 2005) had reconstructions based on fossil taxa that were represented at <60% in the calibration set. To determine if this is effectively a problem, reconstructions should be compared using different models in which fossil samples are better represented.

Here, a reconstruction of the Late Glacial and the early Holocene (>7,000 cal. years BP) periods at Egelsee will be attempted using a North American (NA) (Larocque 2008) and a Swedish TF (Larocque et al. 2001). These particular TFs were selected because: (a) *Corynocera ambigua* is present in 58 of the 100 Swedish training-set lakes and in 15 of the 73 Canadian training-set lakes, (b) taxonomic uniformity was ensured between the training sets and the fossil record, as most samples were analyzed by the same person, (c) at least 80% of the fossil taxa were represented in both training sets in more than 90% of the fossil samples, (d) the temperature gradients in both TFs cover the possible range of temperature during the Late Glacial and the early Holocene at Egelsee, and (e) the study by Lotter et al. (1999) applied a North American training set to a European site. Before applying these TFs to the Egelsee record, their validity will also be assessed by comparing the inferences in varved Lake Silvaplana, Switzerland, obtained with each TF, to instrumental data from Sils-Maria, a meteorological station located on the shore of the lake, following the method presented in Larocque et al. (2009).

Materials and methods

Egelsee (47°11′ N; 8°35′ E, 770 m a.s.l) is a raised bog located 1 km northwest of Menzingen (Kanton Zug) in Central Switzerland. The site is in a region of intensive agriculture. The north slope is covered by a forest dominated by *Abies alba* (Mill.), *Fagus silvatica* (L.), *Pinus silvestris* (L.) and individual stands of *Acer pseudoplatanus* (L.), and *Sorbus aucuparia* (L.) trees or shrubs. Mean annual, July, August and January temperatures are 7, 16, 13, and −2.0°C, respectively (norm values, 1961–1990, data source Meteo Schweiz www.meteoschweiz.ch). More details on the regional setting of this site can be found in Larocque-Tobler et al. (2009a).

The peat thickness of the Egelsee site is 140 cm, representing the last *ca*. 800 years. Under this peat lies gyttja sediment, suggesting a lake existed in the past. Two 12-m-long cores (EGL1–EGL2, 8-cm diameter) were recovered using a modified Livingstone piston corer at the deepest part (11.8 m) of the raised bog. The cores were stored at 4°C until analysed. Twenty-nine samples of terrestrial plant macrofossils (needles, leaves, fruits, twigs, wood, and pieces of cones) from core EGL1 were radiocarbon-dated by the AMS (accelerator mass spectrometry) technique at the Ångström Laboratory, University of Uppsala. The age-depth model is presented in Larocque-Tobler et al. (2009a).

For chironomid analysis, 10% KOH was added overnight to 65 samples of EGL 1, representing the Late Glacial and early Holocene (>7,000 cal. years

BP). The samples were sieved in a 90-µm mesh, the substrate was placed in a Bogorov counting tray, and each head capsule was hand-picked under a binocular microscope at 40× and mounted on a microscope slide. The taxonomy followed Wiederholm (1983), Oliver and Roussel (1983), Larocque and Rolland (2006) and Brooks et al. (2007).

Although reconstruction of Late Glacial and early Holocene temperature was made on assemblages with <60% of the chironomids present in the 101-lake Swiss TF, due to the dominance of *C. ambigua*, two other calibration models were used. The first was a Swedish TF including 100 lakes (Larocque et al. 2001), for reconstructing mean July air temperature. A weighted-average, partial-least-squares (WAPLS) model was developed that had a coefficient of determination (r^2) of 0.65, a prediction error (RMSEP) of 1.13°C, and a maximum bias of 2.1°C. The second model was an eastern North America (NA) TF including 73 lakes (Larocque 2008), used for reconstructing mean August air temperature. The WAPLS model had an r^2 of 0.87, an RMSEP of 1.67°C, and a maximum bias of 2.33°C.

The validity of the NA and the Swedish TFs to accurately reconstruct temperature will be tested by comparing the inferences with instrumental data, following methods presented in Larocque et al. (2009). Lake Silvaplana was used for this test because it is varved, it has a meteorological station located on its shore with instrumental data available back to 1864 AD, and it was shown that the Swiss TF performed well when chironomid-inferred temperatures were compared with instrumental data ($r_{\mathrm{Pearson}} = 0.65$, $p = 0.01$, Larocque et al. 2009). Lake Silvaplana (46°26′56″ N, 9°47′33″ E; 1,791 m a.s.l.) is located in the Engadine, a high-elevation valley in the eastern Swiss Alps. The lake is 3.1 km long and 1.4 km wide. The total surface area is 2.7 km^2. Its average depth is 48 m with the deepest part reaching 77 m. More details on the lake can be found in Bigler et al. (2007), Blass et al. (2007a, b), Trachsel et al. (2008) and Larocque et al. (2009). Although none of the Swiss training set lakes was as deep as Lake Silvaplana, the temperature reconstructions of the last *ca*. 420 years were accurate when compared with early instrumental, historical and dendrochronological data (Larocque-Tobler et al. 2009b).

Results and discussion

Validity of the North American and Swedish transfer functions (TFs)

Table 1 shows the characteristics of the TFs and the two lakes used for: (a) comparison of inferences and instrumental data (Lake Silvaplana) and (b) the Late Glacial temperature reconstruction (Egelsee). The largest temperature gradient (24.5°C) is found in the NA TF and the smallest in the Swedish TF (7.7°C). All three TFs cover the mean July air temperature recorded at Lake Silvaplana (10.8°C), but only the Swiss and the NA TFs cover the temperature registered at Egelsee (16°C). None of the TFs has lakes that are as deep as Lake Silvaplana (77 m) or bogs, but the Late Glacial reconstruction at Egelsee is made using the lacustrine sediment part of the core. Only the Swiss TF has lakes covering the high elevation of Lake Silvaplana (1,791 m a.s.l) while the NA TF has only low-elevation lakes. Even within this context (i.e. a lake deeper than any lake in the training sets), the climate reconstruction seems to be adequate: the

Table 1 Characteristics of the transfer functions and the lakes used for temperature reconstruction

	Swiss TF	Swedish TF	NA TF	Silvaplana	Egelsee
Temperature (°C)	6.9–18.4	7.0–14.7	3.0–27.5	10.8	16
Elevation (m a.s.l.)	418–2,519	169–1,183	13–350	1,791	770
Depth (m)	2.1–49.0	1.5–16.5	1.0–22.0	77	Bog
Model statistics					
r^2	0.8	0.65	0.87		
RMSEP	1.56	1.13	1.67		
Max bias	2.22	2.1	2.33		
Number of taxa	73	48	80		
Month reconstructed	July	July	August		

significant ($p = 0.001$) relationships between chironomid-inferred temperatures and the instrumental data suggest that any of the models could be used to adequately infer mean July air temperature (Fig. 1). The chironomid temperatures inferred by the NA TF had a general pattern of temperature change more similar to the meteorological data ($r_{\mathrm{Pearson}} = 0.71$, $p = 0.001$) than did the Swiss TF ($r_{\mathrm{Pearson}} = 0.65$, $p = 0.001$, Larocque et al. 2009) or the Swedish TF ($r_{\mathrm{Pearson}} = 0.61$, $p = 0.001$). However, the Swiss TF had the greatest number of inferences closer to the instrumental data (i.e. with differences ≤0.5 and 1°C) compared to the other TFs (Table 2), suggesting that this TF provided the best estimates for the last *ca.* 150 years. All TFs provided >60% of inferences that differed from the instrumental data by ≤1°C, suggesting that any of the TFs provides an accurate reconstruction. Many inferences with differences from the instrumental data larger than the RMSEP, were generated with samples that had low percentages of fossil taxa represented in the TFs (Fig. 1), suggesting that the models did not perform as well

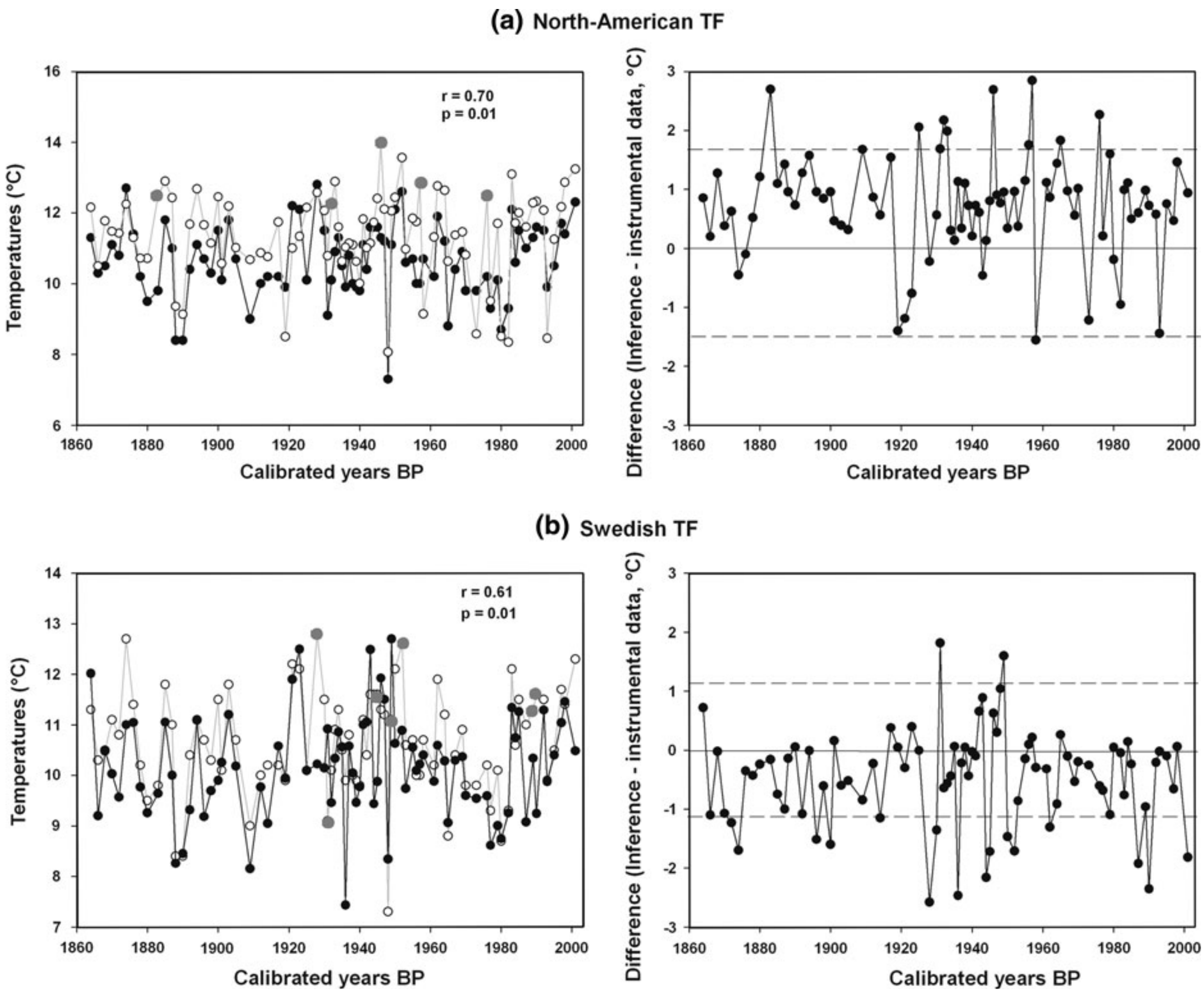

Fig. 1 *Left graphs* Temperature changes during the last *ca.* 150 years measured at the Sils-Maria meteorological station (*black circles*) and inferred by chironomids (*open circles*) preserved in the varved Lake Silvaplana using **a** the North American transfer function reconstructing mean August temperature and **b** the Swedish transfer function reconstructing mean July temperature. The *gray circles* represent samples with <80% of the fossil samples represented in the TFs. The average bias between inferences and instrumental data is 0.7°C. *Right graphs* Differences between the chironomid-inferred temperatures **a** using the North American transfer function, **b** using the Swedish transfer function, and the instrumental data. The horizontal *dotted lines* represent the RMSEP of the transfer functions

Table 2 Percentages of inferences with differences from the instrumental data ≤RMSEP, 1°C or 0.5°C

	Swiss TF	Swedish TF	NA TF
≤RMSEP	87	77	75
≤1°C	78	72	61
≤0.5°C	52	48	22

in the absence of modern analogues (i.e. samples with <80% of fossil taxa represented in the training set). If the good relationship between temperature and chironomid assemblages remained through time, these results suggest that any of the TFs could adequately estimate temperature if the percentage of fossil samples is well represented (80%) in the TFs.

Late Glacial at Egelsee

The Swedish and the NA models yielded similar patterns of temperature change through the Late Glacial, with cold temperatures during the Oldest Dryas (OD), warmer temperatures during the Bølling/Allerød, and colder temperatures during the Younger Dryas (YD) (Fig. 2). However, divergence between the records also occurred. With the Swedish TF, both the OD and the YD were about −2°C colder than the average, but the Allerød was warmer than the Bølling. With the NA transfer function, both the OD and the YD were colder than the average by about −5 and −6°C, respectively, and the Bølling was warmer (+4°C on average) than the Allerød (+2°C on average). The reconstructed climate change pattern was more similar to the GRIP record when the NA transfer function was used (Fig. 2). A similar temperature pattern was also reconstructed using various climate proxies in Europe: by $\delta^{18}O$ in Ammersee, Germany (von Grafenstein et al. 1999), by chironomids in Lago Piccolo di Avigliana, Italy (Larocque and Finsinger 2008), by $\delta^{18}O$ at Hawes Water, northwest England (Jones et al. 2002) and by pollen in two lakes in southwest Italy (Ortu et al. 2008). The reconstruction using chironomids at Lac Lautrey (France) followed the general pattern of temperature reconstructed using the Swiss transfer function, with a colder OD than YD (Heiri and Millet 2005). This similarity between these two records might be due to the fact that both suffered from the same "no-modern analogues" situation due to

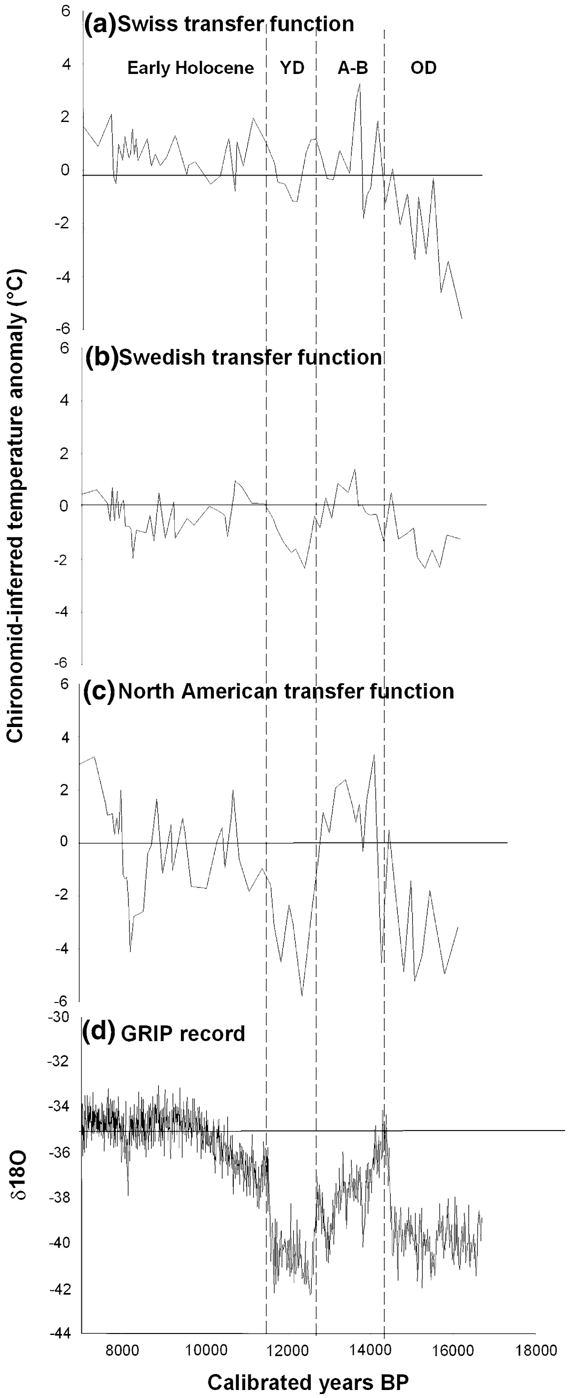

Fig. 2 Chironomid-inferred temperature reconstruction anomaly (i.e. inference—average of the whole record) during the Late Glacial and the early Holocene (>7,000 cal. years BP) using **a** the Swiss, **b** the Swedish, and **c** the North American transfer functions. **d** The $\delta^{18}O$ GRIP record (Rasmussen et al. 2006)

the absence of *Corynocera ambigua* in the Swiss transfer function used for the temperature inferences at both sites.

The amplitude of change from the Allerød to the YD was more plausible with the Swedish TF (−4°C) than the NA TF (−8°C), while changes of about 3–6°C have been reconstructed at the Maloja Pass (1,865 m a.s.l; Ilyashuk et al. 2009), at Gerzensee (603 m a.s.l.) and Leysin (1,230 m a.s.l) (Ammann et al. 2000) in Switzerland. Considering the elevation, the amplitude of changes should be greater at higher-elevation sites (Beniston et al. 1997; Yao et al. 2000), thus the amplitude of change inferred by the chironomids using the NA TF might be too high considering its lower elevation than the Maloja Pass and Leysin sites. The reason why the NA TF yielded changes of larger amplitudes than the Swedish TF was probably due to the temperature optima of taxa included in the training set and present in the fossil record of Egelsee (Fig. 3). Of the 22 taxa present during the Late Glacial, eight (37%) had temperature optima colder than those obtained in the Swedish or the Swiss TF, and six of these taxa (*Paracladius*, *Corynocera ambigua*, *Sergentia*, *Stictochironomus*, *Corynocera oliveri*-type, *Microtendipes*) were abundant (percentages >20%, Fig. 4), leading to colder inferences.

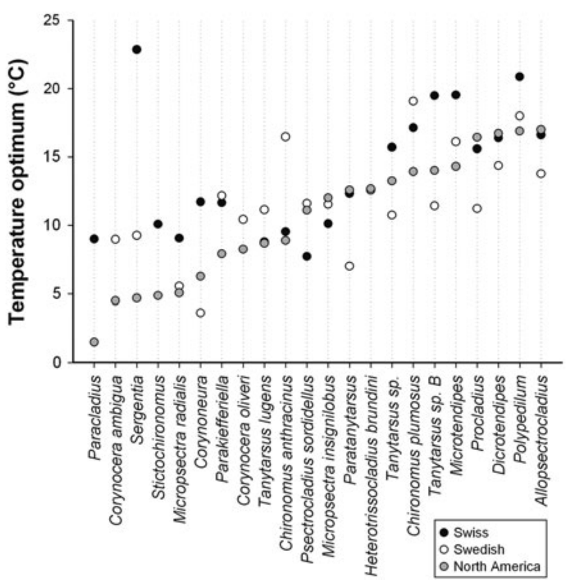

Fig. 3 Temperature optima of the 22 taxa present in the Late Glacial samples of Egelsee. The *black circles* are the temperature optima estimated by the Swiss model, the *open circles* are estimated by the Swedish model and the *gray circles* are estimated by the North American model. The NA optima represent the July temperature (i.e. 2°C were added to the August optima obtained in the model)

Early Holocene

In the early Holocene, the inferred temperatures in Switzerland were generally warmer than the average and sharply decreased around 8,200 cal. years BP (Heiri and Lotter 2005). In the Egelsee record, the 8,200 cal. years BP event was not reconstructed by the Swiss model, probably due to the high percentages (up to 60%, Fig. 3) of *Corynocera ambigua* still present at that time. However, using the Swedish and the NA calibration sets, a decrease of temperature around 8,200 cal. years BP was reconstructed.

The amplitude of change during the 8,200 cal. years BP event was smaller with the Swedish (−2°C) than the North American (−4°C) TF, again probably due to the very low temperature optimum (4.5°C, Fig. 3) of *Corynocera ambigua* in the NA TF.

Corynocera ambigua

Corynocera ambigua has not been found in any of the Swiss training set lakes and was not recorded in any of the 290 Swiss sites compiled by Brigitte Lods-Crozet from the Musée cantonal de Zoologie, Lausanne, Switzerland (http://insects.ummz.lsa.umich.edu/~ethanbr/chiro/chklists/swisslist.html). I found the taxon in varved Lake Silvaplana in very low abundances in samples at *ca*. 1714 AD. In surface samples of training sets, the taxon might be found in cold to intermediate lakes in North America (Barley et al. 2006, Larocque et al. 2006, Porinchu et al. 2009), Finland (Olander et al. 1999), Sweden (Larocque et al. 2001) and Russia (Porinchu and Cwynar 2002). However, it was found in lakes with mean July air temperature reaching more than 20°C in Denmark (Brodersen and Lindegaard 1999). In fossil assemblages, it appears in higher abundances during cold periods (Bedford et al. 2004; Brooks and Birks 2000; Hofmann and Winn 2000; Luoto et al. 2008; Sarmaja-Korjonen et al. 2006; Velle et al. 2005) suggesting that, if temperature does not drive the presence/absence of *Corynocera ambigua*, other factors associated with colder climate do (Larocque-Tobler et al. 2009a). An effort should be made to better understand the factors influencing this complex taxon.

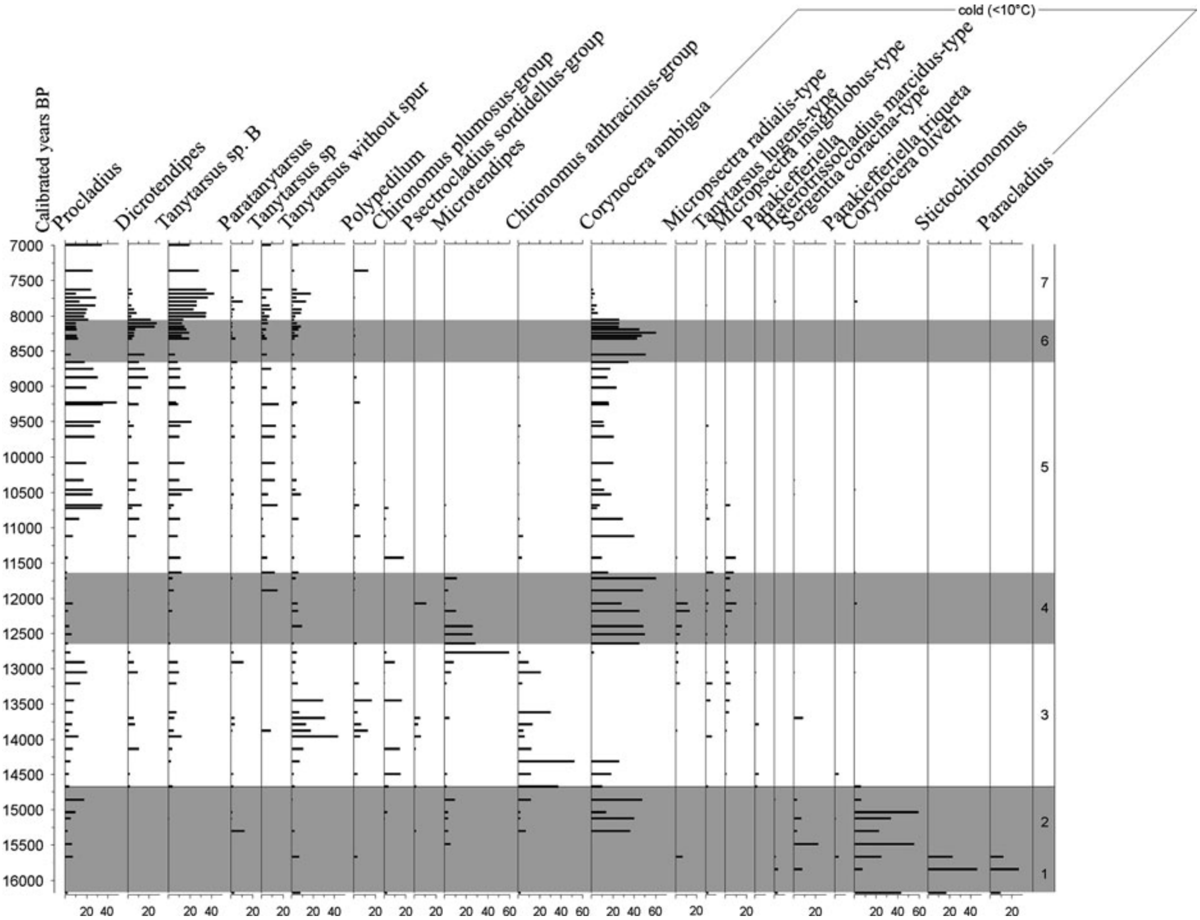

Fig. 4 Percentages of the 22 most common taxa during the Late Glacial and the early Holocene (>7,000 cal. years BP) at Egelsee, Switzerland. The *gray* areas indicate periods of cold inferred climate

Conclusions

When the chironomid-based temperature inferences were compared with instrumental data, the significant relationships ($p = 0.001$) and the small differences ($\leq 1°C$) between the inferences and the instrumental data suggested that all three models could be used to reconstruct temperature over the last century.

On Late Glacial and early Holocene timescales, the use of other TFs with a higher percentage of fossil taxa present in the calibration lakes provided temperature reconstructions that were more similar to other records in Europe and corresponded better to the Greenland GRIP record. Although the NA TF seemed to perform better than the Swedish TF during the Bølling–Allerød period, the amplitude of temperature changes reconstructed by the NA model was larger than expected (e.g. −4°C during the 8,200 cal. years BP event). This larger amplitude was probably due to many taxa having colder temperature optima in the NA TF than in the Swiss and Swedish calibration sets, especially *Corynocera ambigua* which dominated (60%) the assemblages. The results presented here suggest that the general pattern of temperature changes can be adequately reconstructed using a transfer function from another region, but caution should be applied when the amplitude of these changes is considered.

Acknowledgments This research was possible with funding from Swiss National Funds from the Marie-Heim-Vötglin Program. Thanks to Oliver Heiri for providing the Swiss transfer function, to Mark Brenner and two anonymous reviewers for their useful comments.

References

Ammann B, Birks HJB, Brooks SJ, Eicher U, von Grafenstein U, Hofmann W, Lemdahl G, Schwander J, Tobolski K, Wick L (2000) Quantification of biotic responses to rapid climatic change around the Younger Dryas: a synthesis. Palaeogeogr Palaeoclimatol Palaeoecol 159:313–347

Andreev A, Tarasov P, Schwamborn G, Ilyashuk B, Ilyashuk E, Bobrov A, Klimanov V, Rachold V, Hubberten H-W (2004) Holocene palaeoenvironmental records from Nikolay Lake, Lena River Delta, Arctic Russia. Palaeogeogr Palaeoclimatol Palaeoecol 209:197–207

Andreev AA, Tarasov PE, Ilyashuk BP, Ilyashuk EA, Cremer H, Hermichen W-D, Wischer F, Hubberten H-W (2005) Holocene environmental history recorded in the Lake Lyadhej—to sediments, Polar Urals, Russia. Palaeogeogr Palaeoclimatol Palaeoecol 223:181–203

Barley EM, Walker IR, Kurek J, Cwynar LC, Mathewes RW, Gajewski K, Finney BP (2006) A northwest North American training set: distribution of freshwater midges in relation to air temperature and lake depth. J Paleolimnol 36:295–314

Bedford A, Jones RT, Lang B, Brooks S (2004) A late-glacial chironomid record from Hawes water. NW England J Quat Sci 19:281–291

Beniston B, Diaz HF, Bradley RS (1997) Climate change at high elevation sites: an overview. Climatic Change 36:233–251

Bigler C, von Gunten L, Lotter AF, Hausmann S, Blass A, Ohlendorf C et al (2007) Quantifying human-induced eutrophication in Swiss mountain lakes since AD 1800 using diatoms. Holocene 17:1141–1154

Blass A, Bigler C, Grosjean M, Sturm M (2007a) Decadalscale autumn temperature reconstruction back to A.D. 1580 inferred from varved lake sediments of Lake Silvaplana (south-eastern Swiss Alps). Quat Res 68:184–195

Blass A, Grosjean M, Troxler A, Sturm M (2007b) How stable are 20th century calibration models? A high-resolution summer temperature reconstruction for the eastern Swiss Alps back to A.D. 1580 derived from proglacial varved sediments. Holocene 17:51–63

Brodersen KP, Lindegaard C (1999) Mass occurrence and sporadic distribution of Corynocera ambigua Zettersedt (Diptera, Chironomidae) in Danish lakes. Neo and palaeolimnological records. J Paleolimnol 22:41–52

Brooks SJ, Birks HJB (2000) Chironomid-inferred late-glacial air temperatures at Whitrig Bog, southeast Scotland. J Quat Sci 15:759–764

Brooks SJ, Langdon PG, Heiri O (2007) The identification and use of Palaearctic Chironomidae larvae in palaeoecology. QRA Technical Guide No. 10, Quaternary Research Association

Heiri O, Lotter AF (2005) Holocene and Lateglacial summer temperature reconstruction in the Swiss Alps based on fossil assemblages of aquatic organisms: a review. Boreas 34:506–516

Heiri O, Millet L (2005) Reconstruction of Late Glacial summer temperatures from chironomid assemblages in Lac Lautrey (France). J Quat Sci 20:33–44

Hofmann W, Winn K (2000) The littorina transgression in the Weestern Baltic sea as indicated by subfossil Chironomidae (Diptera) and Cladocera (Crustacea). Int Rev Hydrobiol 85:267–291

Ilyashuk EA, Ilyashuk BP, Hammarlund D, Larocque I (2005) Holocene climatic and environmental changes inferred from midge records (Diptera: Chironomidae, Chaoboridae, Ceratopogonidae) at Lake Berkut, southern Kola Peninsula, Russia. The Holocene 15:897–914

Ilyashuk B, Gobet E, Heiri O, Lotter AF, van Leeuwen JFN, van der Knaap WO, Ilyashuk E, Oberli F, Ammann B (2009) Lateglacial environmental and climatic changes at the Maloja Pass, Central Swiss Alps, as recorded by chironomids and pollen. Quat Sci Rev 28:1340–1353

Jones RT, Marshall JD, Crowley SF, Bedford A, Richardson N, Bloemendal J, Oldfield F (2002) A high resolution, multiproxy late-glacial record of climate changes and intrasystem responses in northwest England. J Quat Sci 17:329–340

Langdon PG, Barber KE, Lomas-Clarke SH (2004) Reconstructing climate and environmental change in Northern England through chironomid and pollen analyses: evidence from Talkin Tarn, Cumbria. J Paleolimnol 32:197–213

Larocque I (2008) Nouvelle fonction de transfert pour reconstruire la température à l'aide des chironomides préservés dans les sédiments lacustres. INRS Rapport de Recherche R1032, ISBN 978-2-89146-587-8

Larocque I, Finsinger W (2008) Late-glacial temperature reconstruction using chironomids preserved in Lago Piccolo di Avigliana in the Southern Alps. Palaeogeogr Palaeoclimatol Palaeoecol 257:207–223

Larocque I, Rolland N (2006) Le guide visuel des chironomids sub-fossiles, du Québec à l'île d'Ellesmere, INRS rapport de Recherche R-900, ISBN 2-89146-430-3

Larocque I, Hall RI, Grahn E (2001) Chironomids as indicators of climatic and environmental change: a 100-lake training set from a subarctic region of northern Sweden (Lapland). J Paleolimnol 26:307–322

Larocque I, Pienitz R, Rolland N (2006) Factors influencing the distribution of chironomids in lakes distributed along a latitudinal gradient in northwestern Québec, Canada. Can J Fish Aquat Sci 63:1286–1297

Larocque I, Grosjean M, Heiri O, Bigler C, Blass A (2009) Comparison between chironomid-inferred July temperatures and meteorological data AD 1850–2001 from varved Lake Silvaplana, Switzerland. J Paleolimnol 41:329–342

Larocque-Tobler I, Heiri O, Wehrli M (2009a) Late Glacial and Holocene temperature changes at Egelsee, Switzerland, reconstructed by chironomids (non-biting midges). J Paleolimnol. doi 10.1007/s10933-009-9358-z

Larocque-Tobler I, Grosjean M, Heiri O, Trachsel M (2009b) High-resolution mean July air temperature history since AD 1580 as reconstructed by chironomids preserved in varved Lake Silvaplana, Engadine, Switzerland. The Holocene 19:1201–1212

Levesque AJ, Cwynar LC, Walker IR (1996) Richness, diversity and succession of late-glacial chironomid assemblages in New Brunswick, Canada. J Paleolimnol 16:257–274

Lotter AF, Birks HJB, Hofmann W, Marchetto A (1998) Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. II. Nutrients. J Paleolimnol 19:443–463

Lotter AF, Walker IR, Brooks SJ, Hofmann W (1999) An intercontinental comparison of chironomid palaeotemperature inference models: Europe vs North America. Quat Sci Rev 18:717–735

Luoto TP, Nevalainen L, Sarmaja-Korjonen K (2008) Multiproxy evidence for the 'Little Ice Age' from Lake Hampträsk, Southern Finland. J Paleolimnol 40:1097–1113

Olander H, Birks HJB, Korhola A, Blom T (1999) An expanded calibration model for inferring lake water and air temperatures from fossil chironomid assemblages in northern Fennoscandia. Holocene 9:279–294

Oliver DR, Roussel ME (1983) The insects and arachnids of Canada. Part II. The genera of larval midges of Canada. Publication 1746. Agriculture Canada, 263 pp

Ortu E, Peyron O, Bordon A, de Beaulieu JL, Siniscalco C, Caramiello R (2008) Lateglacial and Holocene climate oscillations in the south-western Alps: an attempt at quantitative reconstruction. Quat Int 190:71–88

Porinchu DF, Cwynar LC (2002) Late-quaternary history of midge communities and climate from a tundra site near the lower Lena River, Northeast Siberia. J Paleolimnol 27:59–69

Porinchu D, Rolland N, Moser K (2009) Development of chironomid-based air temperature inference model for the Central Canadian Arctic: incorporating high resolution gridded climate data. J Paleolimnol 41:349–368

Sarmaja-Korjonen K, Nyman M, Kultii S, Väliranta M (2006) Paleolimnological development of Lake Njagajavri, northern Finnish Lapland, in a changing Holocene climate and environment. J Paleolimnol 35:65–81

Trachsel M, Eggenberger U, Grosjean M, Blass A, Sturm M (2008) Mineralogy-based quantitative precipitation and temperature reconstructions from annually laminated lake sediments (Swiss Alps) since AD 1580. Geophys Res Lett 35:L13707. doi:10.1029/2008GL03412

Velle G, Larsen J, Eide W, Peglar SM, Birks HJB (2005) Holocene environmental history and climate of Ratasjoen, a low alpine lake in south-central Norway. J Paleolimnol 33:129–153

von Grafenstein U, Erlenkeuser H, Brauer A, Jouzel J, Johnsen S (1999) A mid-European decadal isotope climate record from 15, 500 to 5000 years BP. Science 284:1654–1657

Walker IR, Levesque AJ, Cwynar LC, Lotter AF (1997) An expanded surface-water palaeotemperature inference model for use with fossil midges from eastern Canada. J Paleolimnol 18:165–178

Wiederholm T (ed) (1983) Chironomidae of the holarctic region. Keys and diagnoses. Part 1—Larvae. Entomologica Scandinavia (supplement 19) 457 pp

Yao T, Liu X, Wang N, Shi Y (2000) Amplitude of climatic changes in Qinghai-Tibetan Plateau. Chin Sci Bull 45:1236–1243